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Editorial

Editorial to the Special Issue: "Recent Advances in Gamma Ray Astrophysics and Future Perspectives" †

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This Special Issue is a collection of reviews highlighting the recent progress in the very vast and closely related fields of γ-ray astrophysics and astro-particle physics in recent years, looking toward a very promising future. Unsurprisingly, given that active galactic nuclei (AGN) represent 50% of the sources detected at high energies (100 MeV $<$ E $<$ 100 GeV) [and 3% of those detected at very high energies (E $>$ 100 GeV)] [1], most papers in this Issue deal with cosmic sources of extra-galactic origin. As such, they adhere to my own selection of topics, which is by definition incomplete and understandably affected by personal biases. Nevertheless, I hope that they may be valuable for a broad audience that does not necessarily specialise in γ-ray astrophysics, as they were intended to, and I sincerely thank each author who took the time out their already overcrowded schedules and accepted my invitation to contribute to this effort.

AGNs are galaxies whose centers host an accreting supermassive black hole ($M_{\rm BH} \sim 10^6$–$10^{10}\,{\rm M}_{\odot}$), which generates luminosities of up to $10^{46}\,{\rm erg\,s^{-1}}$ through non-thermal mechanisms. They can be observed throughout the entire electromagnetic spectrum from the radio to γ-rays and are generally classified into different types according to the presence and width of the emission lines in their optical spectra. Blazars, in particular, are recognized as having their jets pointed towards the observers (within 10–15°), and are hence strongly connected to γ-ray emission. These can be subdivided into flat-spectrum radio quasars (FSRQ) and BL Lac objects, with the latter showing almost featureless continua (see [2] for a recent review).

In this context, the paper "Gamma-ray Emission and Variability Processes in High-Energy-Peaked BL Lacertae Objects" by Kapanadze (contribution 1) presents a thorough review of the non-thermal mechanisms that dominate the emissions from high-energy peaked BL Lacs, which can reach the VHE regime, highlighting the fundamental role of γ-ray variability in discriminating the individual processes. The scope of this review is not confined to high-energy peaked BL Lacs, howevers, as the emission mechanisms described are applicable to most jetted extragalactic sources.

One of the main common characteristics of the different types of AGN, which is relevant in order to understand their physics, is indeed the set of properties of their relativistic jets. In "The power of relativistic jets: a comparative study" by Foschini et al. (contribution 2), the authors provide a detailed comparison of different methods to estimate the jet power, and present a set of equations in order to evaluate this important parameter. This set, taken with the proper caveats, also represents a very useful tool-box for young researchers who are starting their studies in the field of jetted sources.

The paper "Highlights of the MAGIC Florian Goebel Telescopes in the study of Active Galactic Nuclei" by Manganaro and Dominis Prester (contribution 3) reviews the main achievements obtained in the field of AGN by the MAGIC [3] Telescopes, one of the sets of the current generation of Imaging Atmospheric Cherenkov Telescopes (IACTs), which includes VERITAS [4] and H.E.S.S. [5]. Indeed, MAGIC discovered six out of the ten VHE-emitting FSRQs, two of which close to a redshift of one, thus enabling fundamental studies of the extra-galactic background light (EBL). Among the tens of AGNs detected by MAGIC, the blazar TXS 0506+056 is worthy of mention, as it was found to be in a flaring state at several wavelengths, almost in coincidence with the neutrino event IceCube-170922A. A lepto-hadronic emission model is favoured in order to explain the full spectral energy distribution.

The paper "A very-high-energy gamma-ray view of the transient sky" by Carosi and López-Oramas (contribution 4) provides an in depth review of the Galactic and extragalactic HE and VHE transients, mostly related to stellar-size compact objects, including novae, microquasars and flaring gamma-ray binaries, supernovae, pulsar-wind nebulae, fast radio bursts and magnetars, and gravitational waves, and also touching upon gamma-ray bursts and tidal disruption events. The observational corpus for each of these, obtained thanks to the current generation of IACTs, is presented and the proposed underlying physical processes are reported. The review provides a broad view of how the physics of these VHE transients is tightly connected with time-domain and multi-messenger astronomy, and what the next generation of IACTs will contribute to this research field.

The next generation of IACTs will commence with the advent of the Cherenkov Telescope Array Observatory (CTAO, [6]) which, with its wide (20 GeV–300 TeV) energy range and unprecedented sensitivity (5–20 times better with respect to the current IACTs), will improve our grasp of the VHE phenomena by leaps and bounds. In the meantime, a few precursors are being built and tested. Among them is the ASTRI Mini-Array, which will be the largest IACT array in operation until CTAO is completed. During the first four years of operation, it will be run in experiment mode, starting in late 2025, and will investigate a few fundamental open VHE questions by performing dedicated deep observations of specific sky regions. In the following phase, the ASTRI Mini-Array will be run as an Observatory, open to proposals from the whole scientific community, and it is expected to investigate both galactic and extra-galactic sources. The two papers "The ASTRI Mini-Array: a new pathfinder for Cherenkov Telescope Arrays" by Scuderi (contribution 5) and "Science with the ASTRI Mini-Array: From Experiment to Open Observatory" by Vercellone (contribution 6) detail the challenges faced and the innovative solutions adopted for the construction, operation, and maintenance of the nine IACTs that will form the array, as well as the expected performance and scientific outcomes that will be afforded based on its wide energy range (1–200 TeV), large field of view ($\sim 10^\circ$), angular resolution ($\sim 3'$), and energy resolution ($\sim 10\%$).

AGILE (2007–2024) was one of the major HE space missions in the first two decades of this century, after the Energetic Gamma Ray Experiment Telescope (EGRET, [7]) on board Compton Gamma-Ray Observatory. The review "Scientific Highlights of the AGILE Gamma-ray Mission" by Vercellone, Pittori, and Tavani (contribution 7) presents the instrument and some of the major scientific discoveries and achievements obtained during its seventeen years of operation in both the Galactic and extra-galactic fields. Among those is the discovery of the Crab Nebula variability in the energy range above 100 MeV and the first evidence of hadronic cosmic-ray acceleration in supernova remnants. Both results had a profound impact on the scientific community, especially on theoretical modelling, and they are also important for observations at higher energies with current and future Cherenkov and extended air-shower arrays.

One of the main targets of γ-ray astrophysics, since the beginning of its existence, has been supernova remnants (SNRs) due to their potential link to cosmic ray (CR) sources. The paper "Supernova remnants in gamma rays" by Giuliani and Cardillo (contribution 8) reviews the results obtained regarding SNRs from observations in the GeV, TeV, and PeV bands and the still open questions regarding their contribution to the population of Galactic CRs.

Gamma-ray bursts (GRBs) are often reported as the being the most energetic explosive phenomena in the universe. Understanding GRBs requires the contribution of most astrophysical fields, ranging from stellar evolution to jet formation, from the equation of state of supra-density matter to gravitational waves, helping to explain the scientific community's fascination with them since their discovery. The paper "Gamma-Ray Bursts: 50 Years and Counting!" by Vigliano and Longo (contribution 9) is a riveting historical review of the progress in this study, from GRBs' serendipitous discovery to the modern day, and demonstrates how this progress is tightly bound to the advances in the technological field, driven by the need to answer the questions that continually arise from new discoveries and theoretical models. The paper also summarises the current open questions in the field, and offers a strong motivation for new technological ventures.

As an upbeat conclusion, the paper "Future perspectives for gamma ray bursts investigations from space" by Bozzo et al. (contribution 10) offers a detailed review of many of the future space missions that will be devoted to the investigation of GRBs in the coming years, describing their specifications and their expected scientific impact in the field. It includes the Einstein Probe (launched on 9 January 2024), the enhanced X-ray Timing and Polarimetry (eXTP) mission, the Gamow Explorer, the High-z gamma-ray bursts for unraveling the dark ages mission (HiZ-GUNDAM), the LargE Area burst Polarimeter (LEAP), the Moon Burst Energetics All-sky Monitor (MoonBEAM), POLAR-2, the StarBurst Multimessenger Pioneer, the Spectroscopic Time-Resolving Observatory for Broadband Energy X-rays (STROBE-X), the Space-based Variable astronomical Object Monitor (SVOM), and the Transient High-Energy Sky and Early Universe Surveyor (THESEUS).

In closing, I believe that, as a whole, this volume shows how, from the strong foundations pioneered by the past and pursued by the current generations of ground- and space-based instrumentation, a new era is about to begin that will foster new missions, experiments, and observatories, which will satisfy the scientific curiosity of the γ-ray astrophysics and astro-particle physics communities in the years to come.

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Abbreviations

The following abbreviations are used in this manuscript:

AGILE	Astrorivelatore Gamma ad Immagini LEggero
AGN	Active Galactic nuclei
ASTRI	Astrofisica con specchi a tecnologia replicante italiana
CGRO	Compton Gamma-Ray Observatory
CTAO	Čerenkov telescope array Observatory
EGRET	Energetic Gamma Ray Experiment Telescope
EP	Einstein Probe
eXTP	enhanced X-ray Timing and Polarimetry mission
FSRQ	Flat-spectrum radio quasar
GRB	Gamma-ray burst
HE	High-energy
HiZ-GUNDAM	High-z gamma-ray bursts for unraveling the dark ages mission
LEAP	LargE Area burst Polarimeter
MAGIC	Major atmospheric gamma-ray imaging Čerenkov Florian Goebel telescopes
MDPI	Multidisciplinary Digital Publishing Institute
MoonBEAM	Moon Burst Energetics All-sky Monitor
SNR	Supernova remnant
STROBE-X	Spectroscopic Time-Resolving Observatory for Broadband Energy X-rays
SVOM	Space based Variable astronomical Object Monitor
THESEUS	Transient High-Energy Sky and Early Universe Surveyor
VHE	Very high-energy

List of Contributions

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